



Construction of the Projection Optics Box for the Engineering Test Stand

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Contributions from

Lawrence Livermore National Laboratory

Sandia National Laboratory

Lawrence Berkeley National Laboratory

EUV LLC

International SEMATECH

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Contributors

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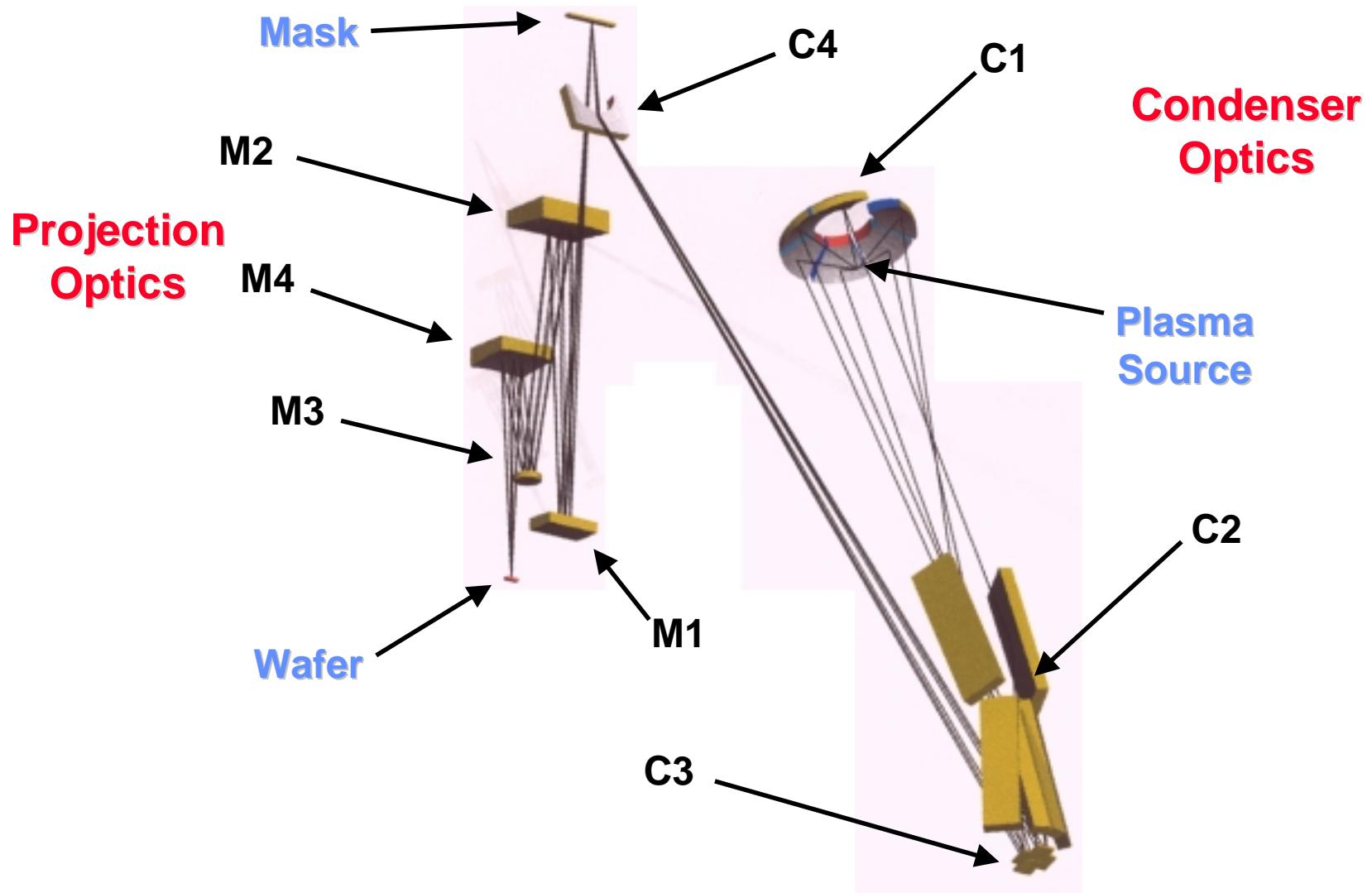
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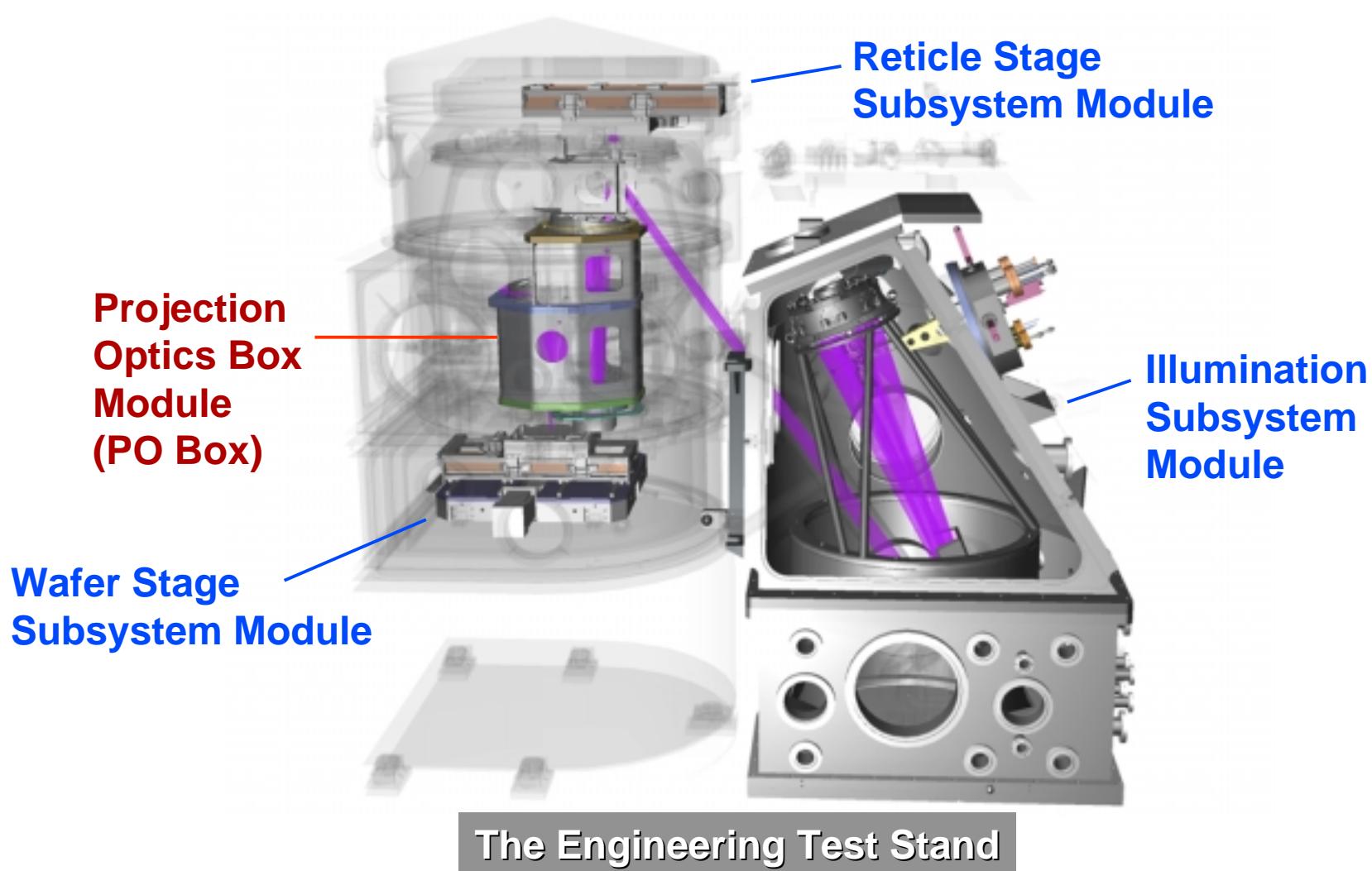
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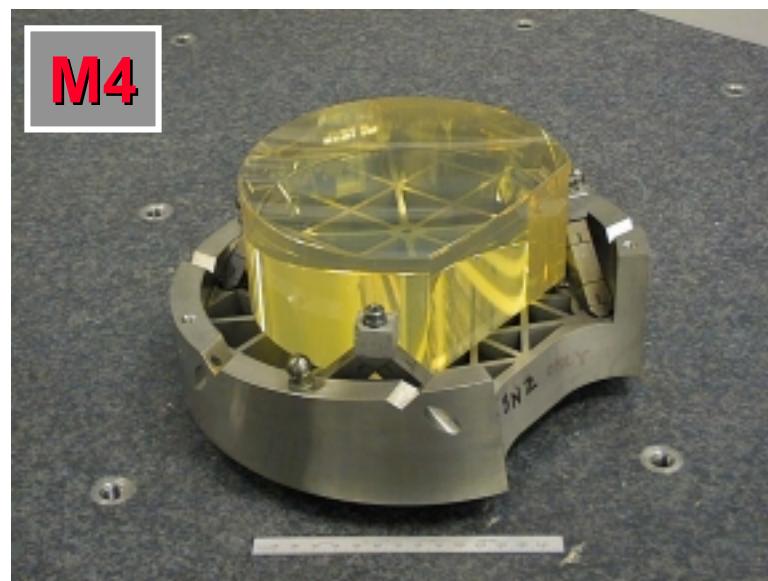
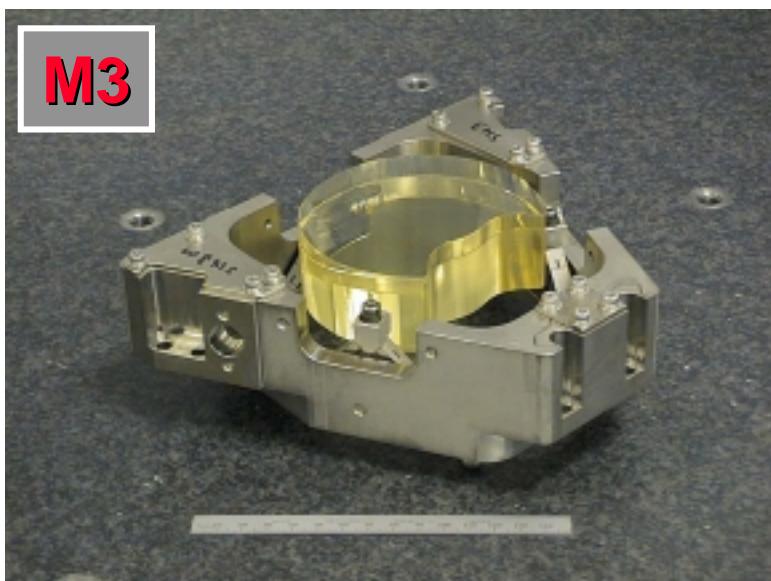
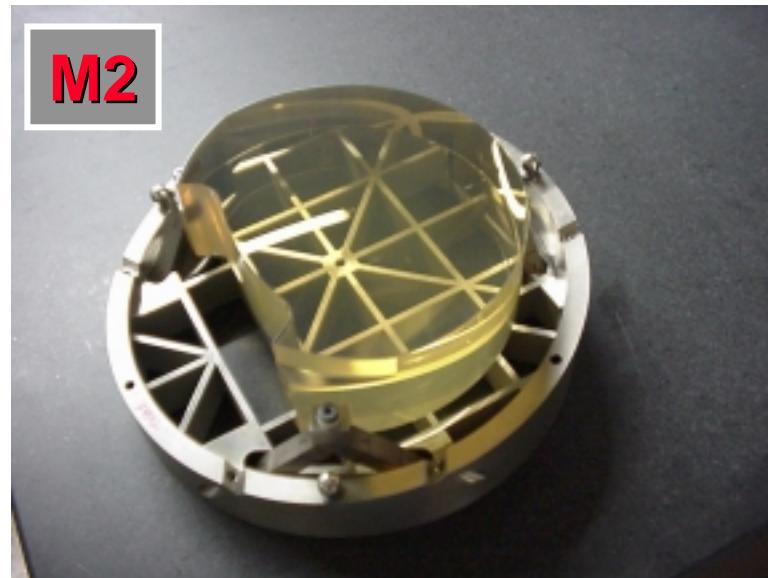
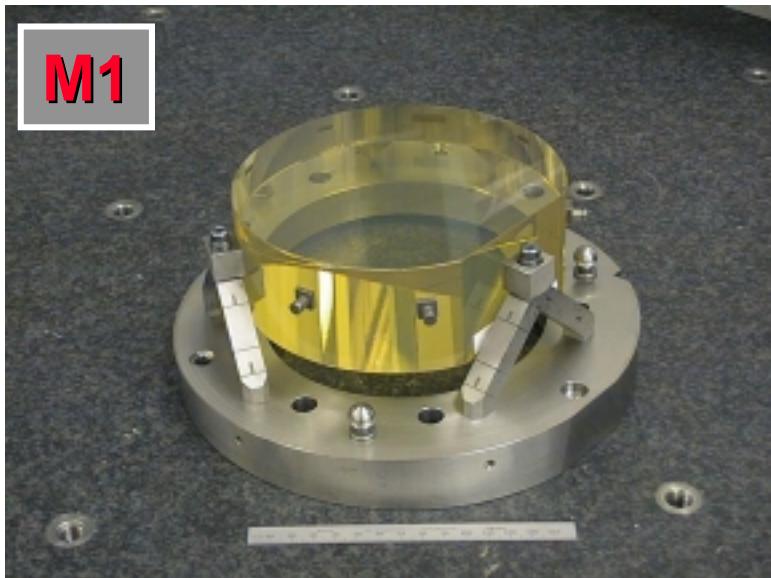
The Engineering Test Stand employs Köhler-critical illumination and a 0.1 NA ring-field imaging system



The alpha-class ETS will produce initial EUV scanned images in April 2001

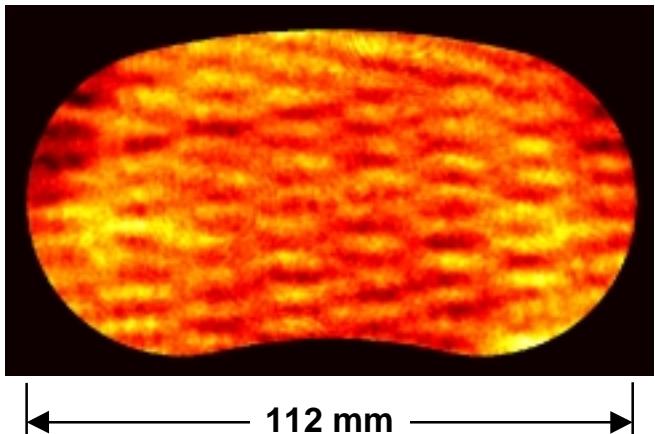


SVG-Tinsley has delivered Optics Set 2

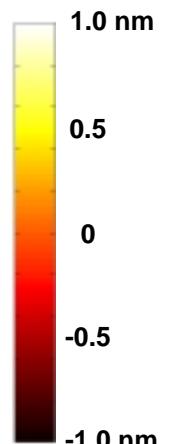
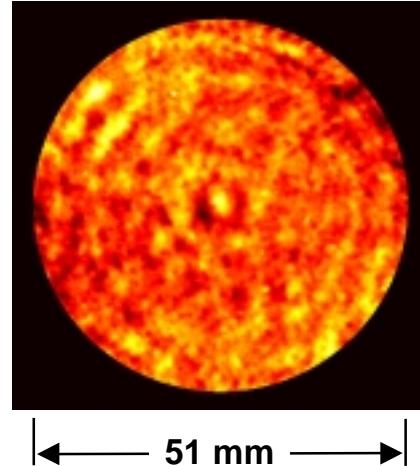


SVG-Tinsley achieved excellent figure control on Optics Set 2

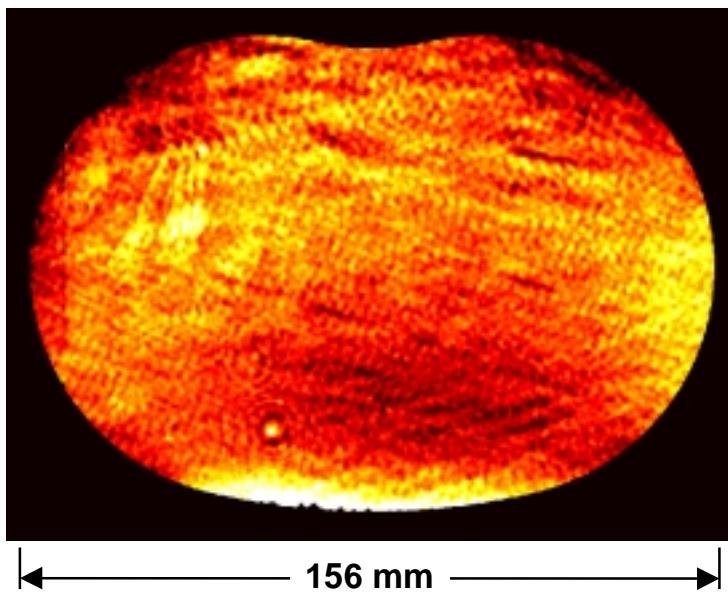
M1 Figure: 0.25 nm rms



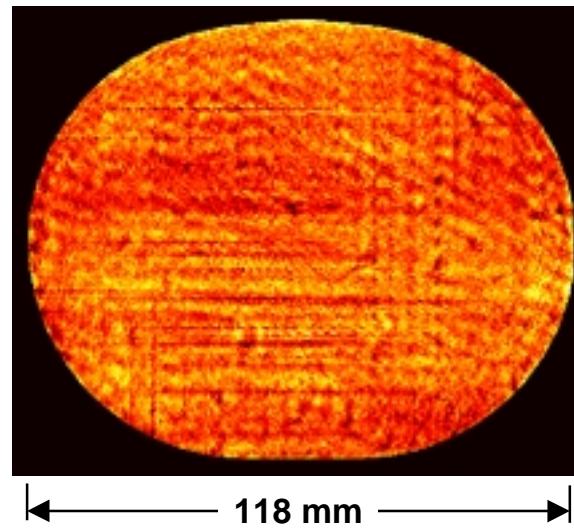
M3 Figure: 0.22 nm rms



M2 Figure: 0.35 nm rms



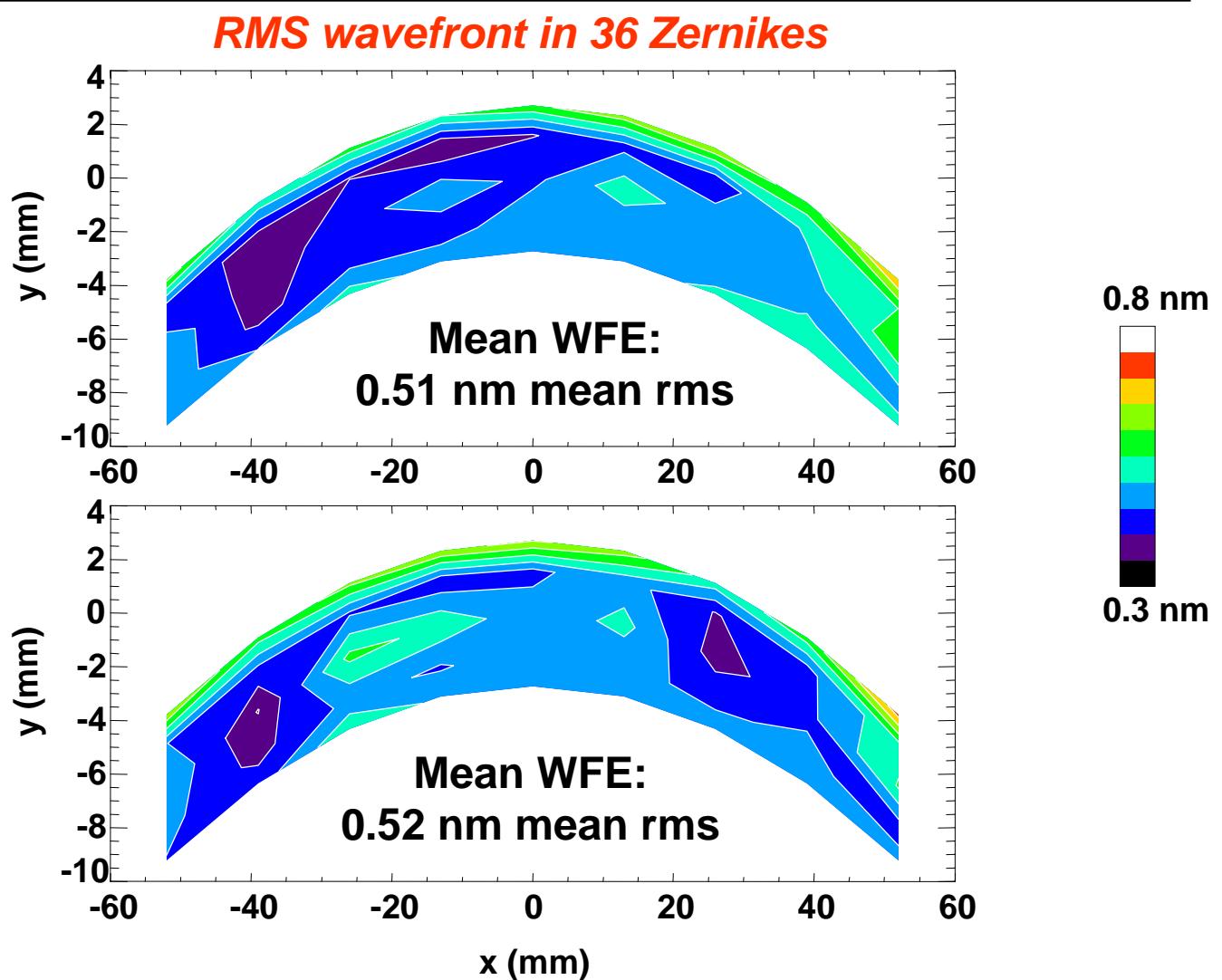
M4 Figure: 0.25 nm rms



M2 cutting distortion does not significantly affect the imaging performance of PO Box 2

M2 figure:

Before cutting:
0.23 nm rms



M2 figure:

After cutting:
0.35 nm rms

Similar conclusions are reached for: distortion,
contrast (70 nm dense + flare), CD uniformity

Optics Set 2 achieves low levels of figure error and MSFR

M1

Figure: 0.25 nm rms

MSFR: 0.21 nm rms

HSFR: 0.24 nm rms

M2

Figure: 0.35 nm rms

MSFR: 0.20 nm rms

HSFR: 0.19 nm rms

M3

Figure: 0.22 nm rms

MSFR: 0.15 nm rms

HSFR: 0.24 nm rms

M4

Figure: 0.25 nm rms

MSFR: 0.22 nm rms

HSFR: 0.17 nm rms

Specifications:

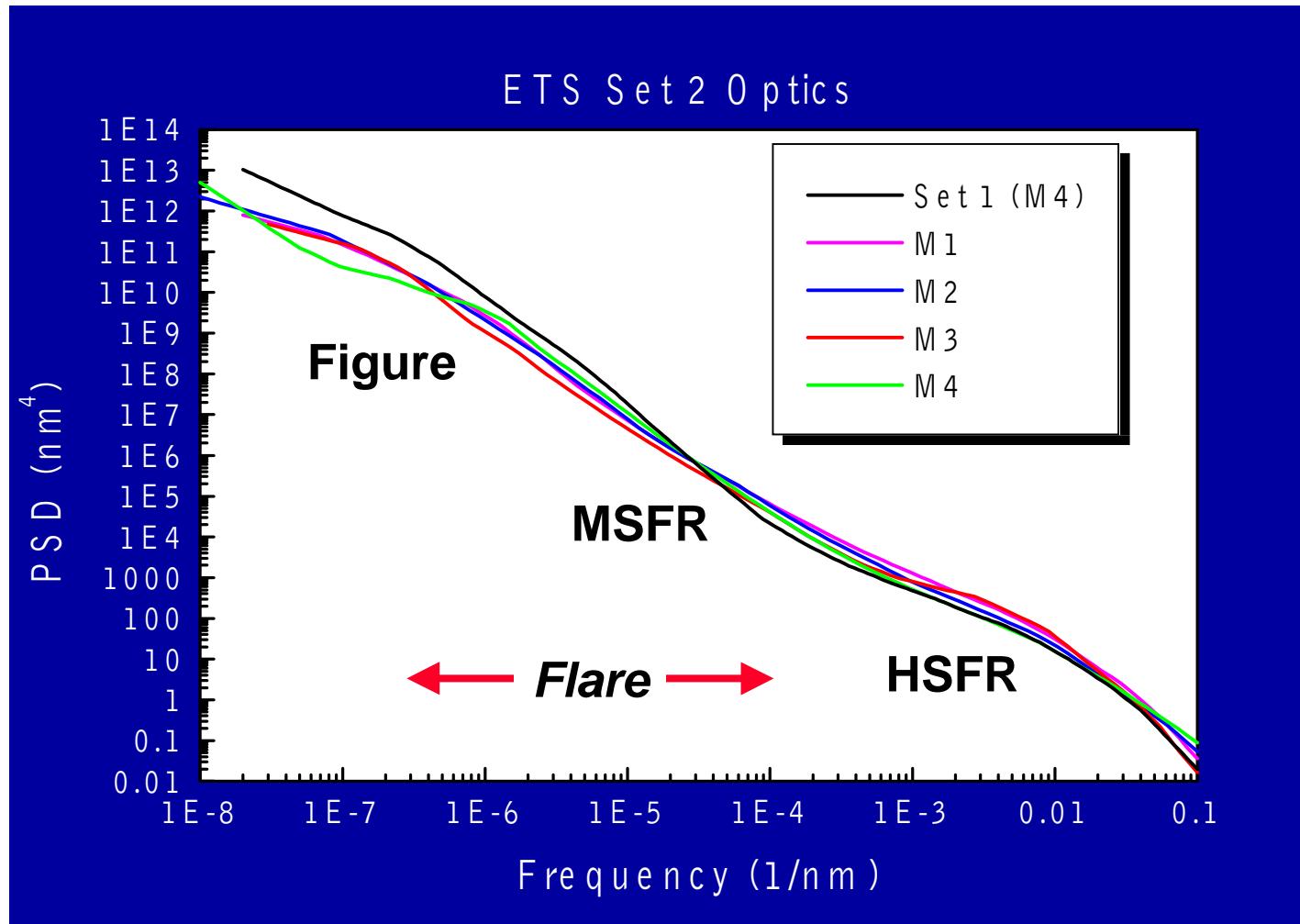
Figure: 0.25 nm rms

MSFR: 0.20 nm rms

HSFR:

- EUV Goal: 0.10 nm rms
- Best to-date: 0.13 nm rms
(Zerodur flat, aspheric tool)

PSDs of the Set 2 substrates illustrate great improvement over Set 1 in figure and MSFR

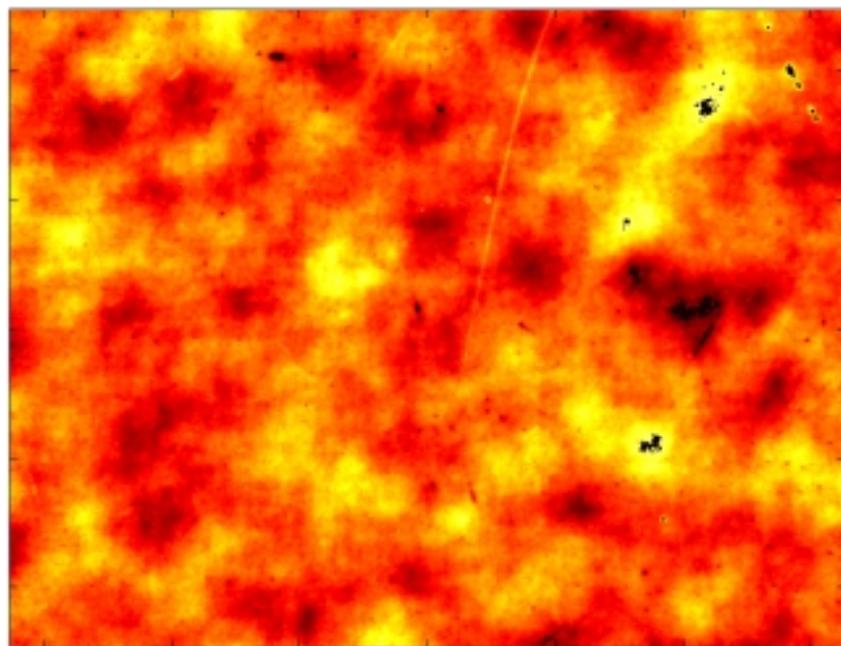


**Optics Set 2 has greatly improved “1-mm waviness”
and promises significantly lower flare**

Phase Measuring Microscopy (2.5x Objective)

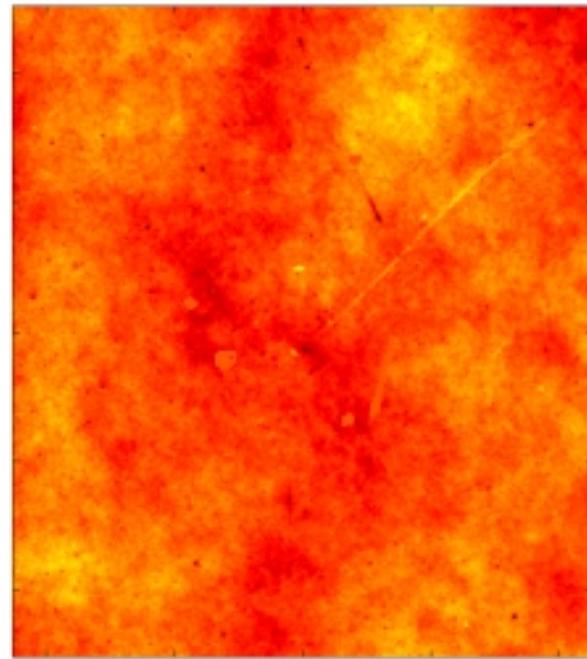
M1 Optics Set 1

P-V = 8.8 nm RMS = 0.37 nm



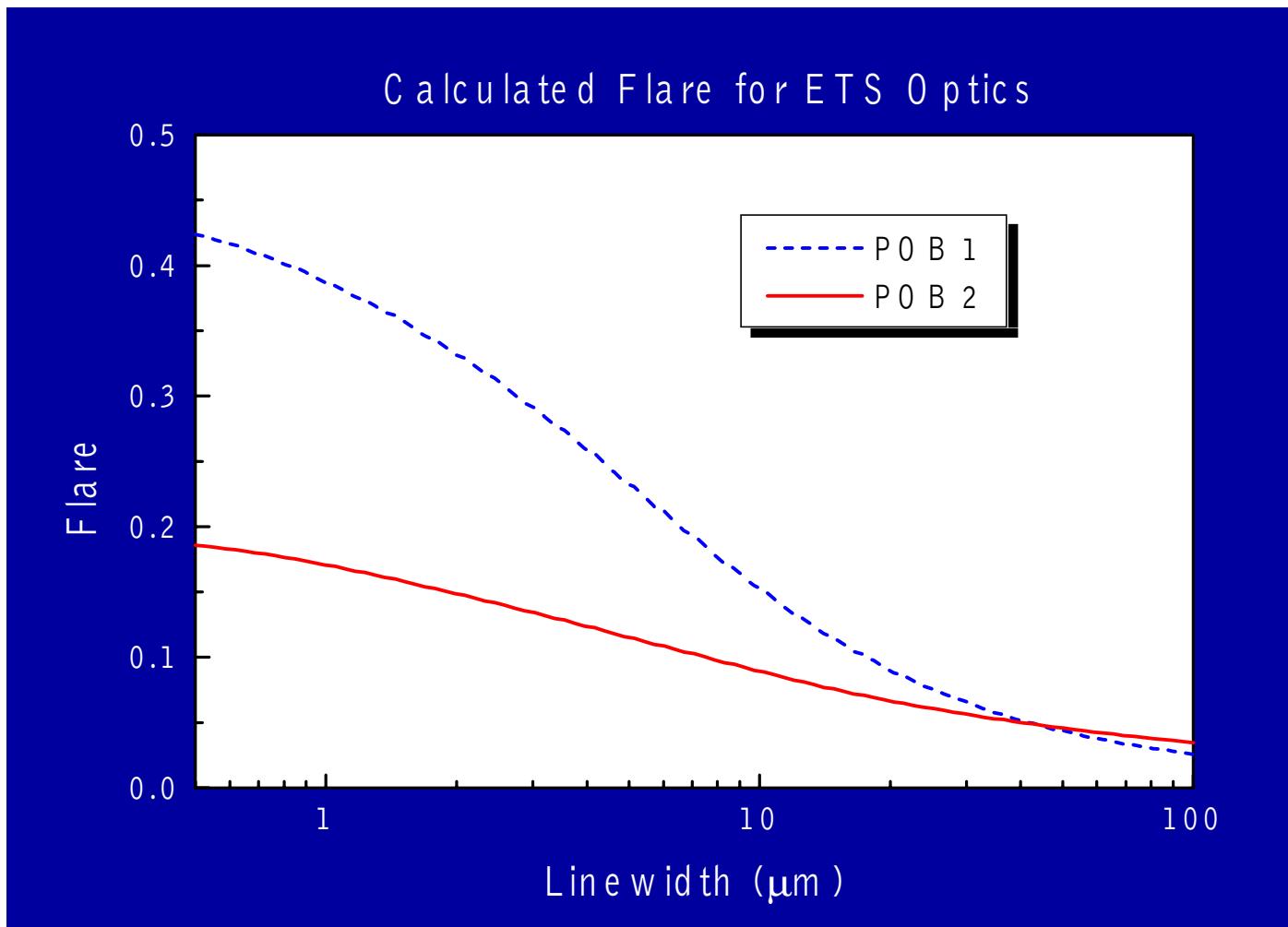
M1 Optics Set 2

P-V = 2.8 nm RMS = 0.21 nm



+1.5 nm -1.5 nm

PO Box 2 will have less than half of the flare of PO Box 1



Higher levels of HSFR lead to reduced throughput

Camera throughput estimation for Zerodur™ substrates

Ideal Surface: 0.10 nm rms
Reflectivity (Mo/Si) = 66.7%
Throughput (R^4) = 20%

Superpolished Flat

Best Test Sample: 0.13 nm rms
Reflectivity = 66.3%
Throughput = 19%

Development Goal

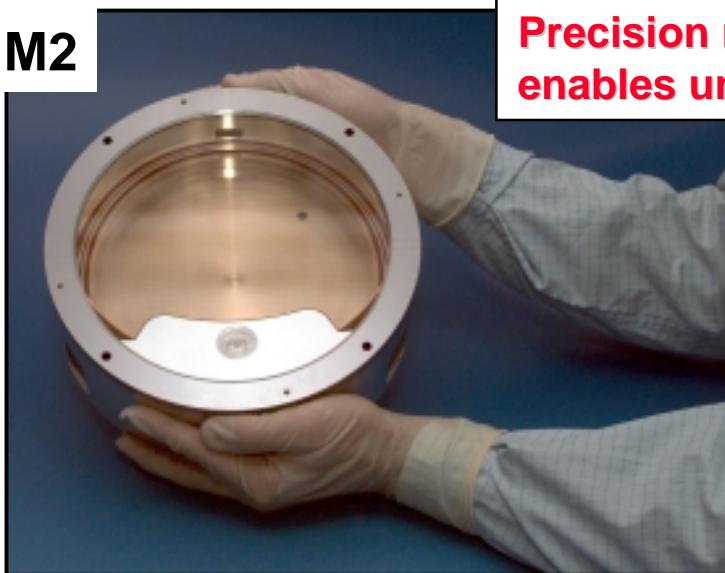
Optics Set 1: 0.17 nm rms (ave)
Reflectivity = 65.5% (ave)
Throughput = 18.4%

Continued polishing development could attain a 9% increase in throughput

Optics Set 2: 0.21 nm rms (ave)
Reflectivity = 64.5% (ave)
Throughput = 17.3%

The multilayer coating team will extend Optics Set 1 experience to Optics Set 2

M2



Precision mechanical design
enables uniformity control

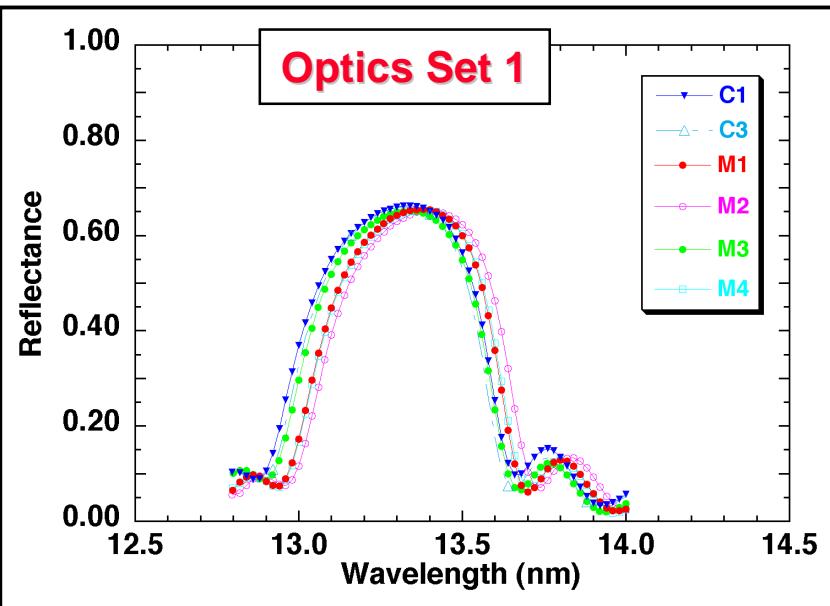
Excellent Set 1 Uniformity

M2

$\pm 0.1\%$



96 mm



Wavelength matching for Set 1:

$$1\sigma = 0.032 \text{ nm} = 0.32\text{\AA}$$

Integrated throughput of 96% compared to ideal

Peak centroid for Set 1 = 13.34 nm

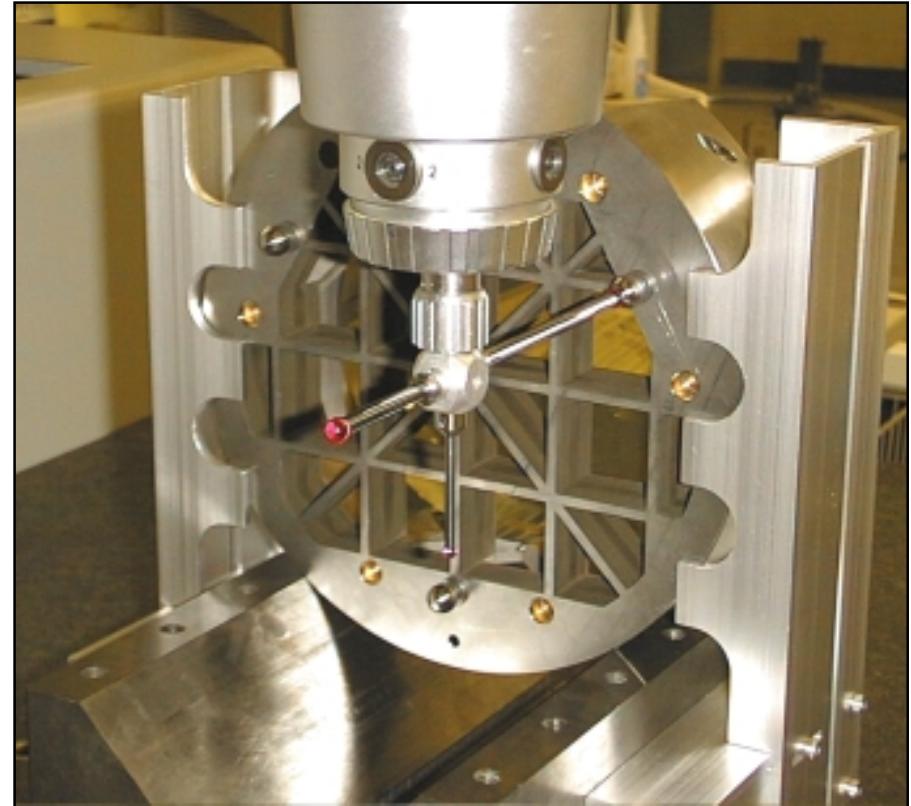
→ This is the target for PO Set 2

Mechanical alignment begins with registering the tooling features with respect to the optical surface

PO Box 1 Mechanical Assembly



Location of datums on
optical substrate



Transfer of datums to
mounting hardware

PO Box 2 is ready for assembly and mechanical-alignment



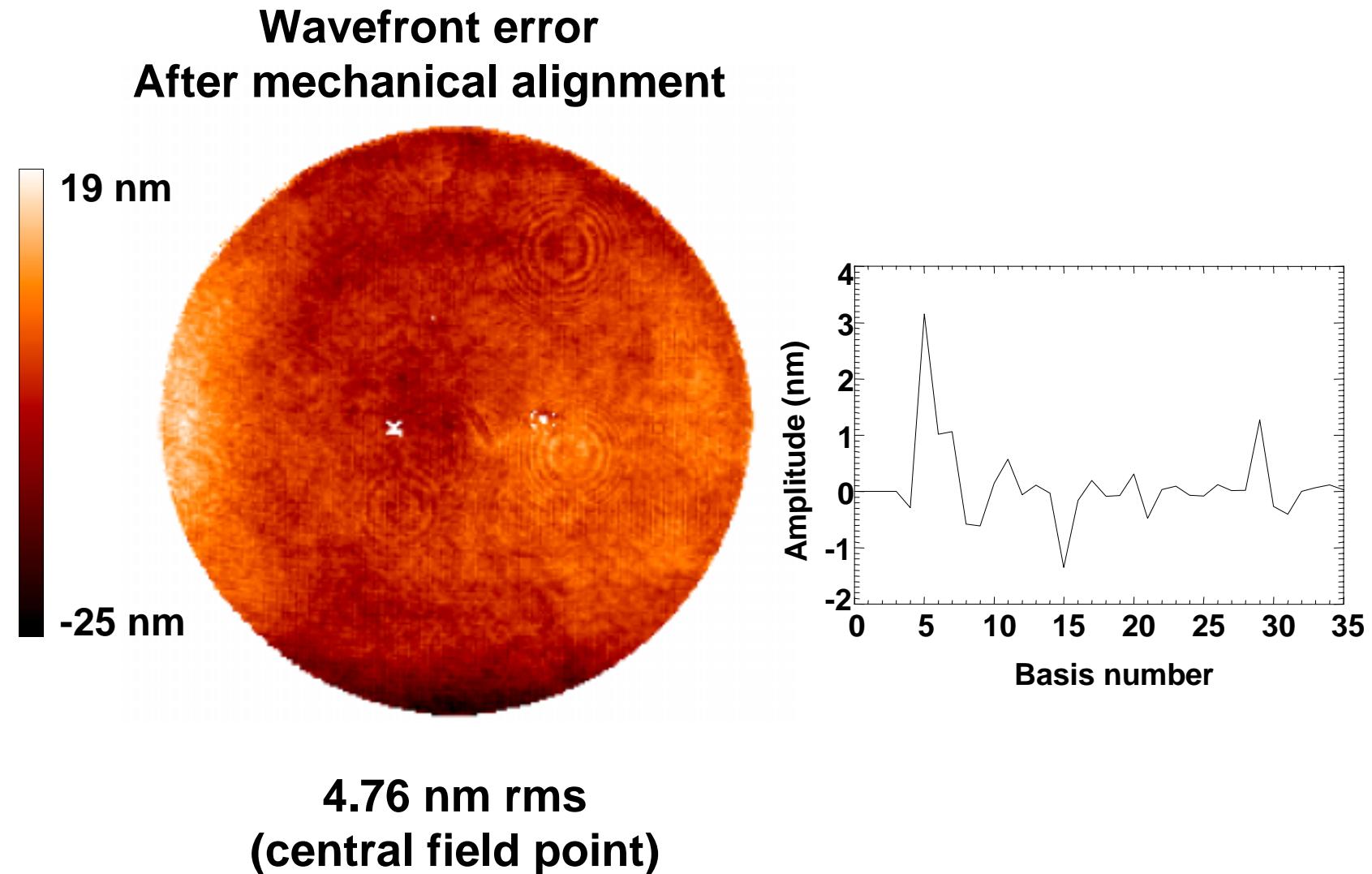
**PO Box 2 undergoing inspection on
coordinate measuring machine**

The *capture tolerances* define the accuracy required of the mechanical alignment of optics

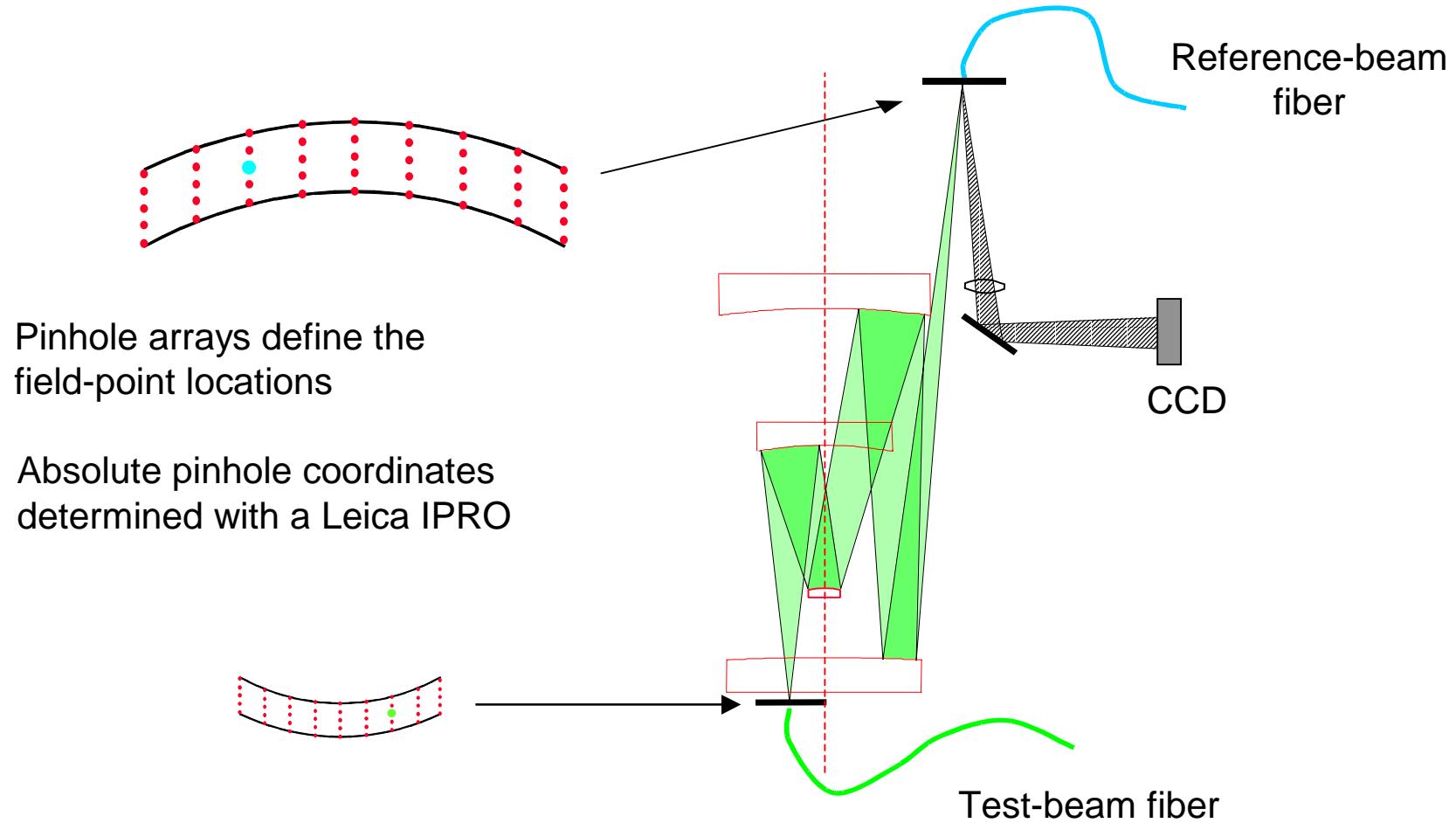
Optics initially aligned to capture tolerances will allow the system to reach final alignment in the system interferometer using the remotely actuated compensators

Degree of Freedom	Capture Tolerance	Estimated Accuracy
X	$\pm 110 \mu\text{m}$	$\pm 80 \mu\text{m}$
Y	$\pm 110 \mu\text{m}$	$\pm 80 \mu\text{m}$
Z	$\pm 270 \mu\text{m}$	$\pm 20 \mu\text{m}$
θ_x	$\pm 220 \mu\text{rad}$	$\pm 60 \mu\text{rad}$
θ_y	$\pm 220 \mu\text{rad}$	$\pm 60 \mu\text{rad}$

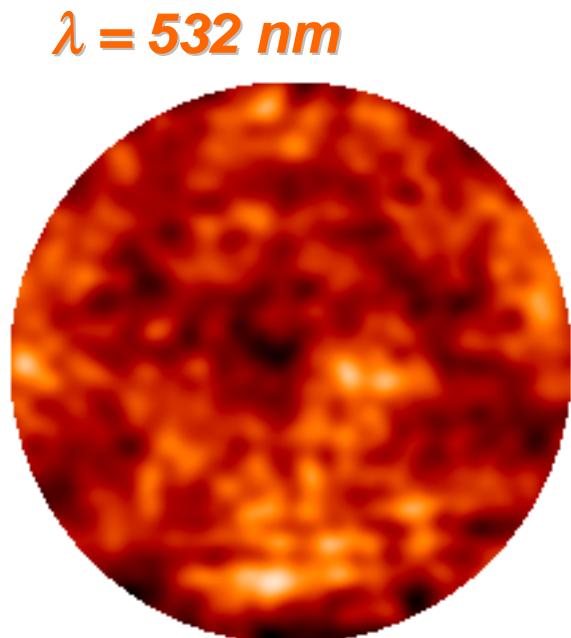
Our mechanical assembly was well within capture tolerance of the alignment algorithm



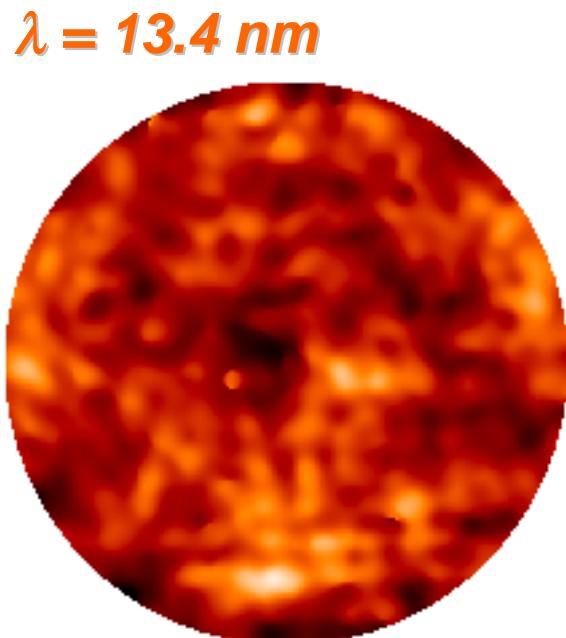
WFE and distortion are measured with a visible-light phase-shifting point-diffraction interferometer



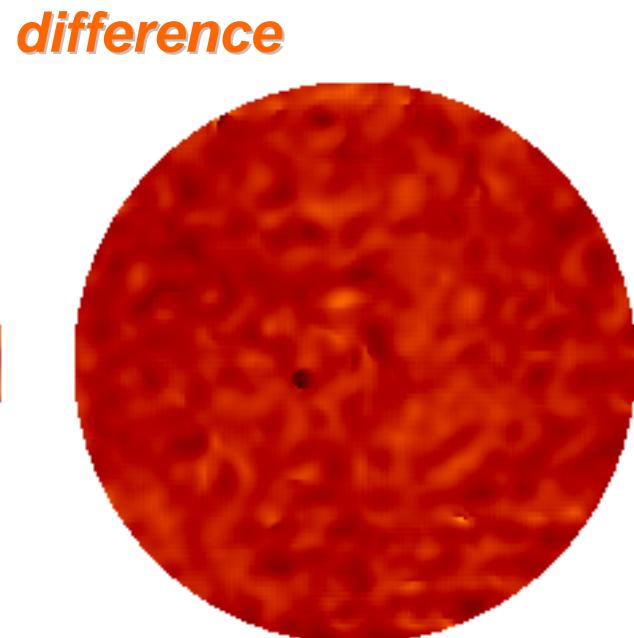
The agreement between visible and EUV interferometry is excellent



1.61 nm rms



1.65 nm rms



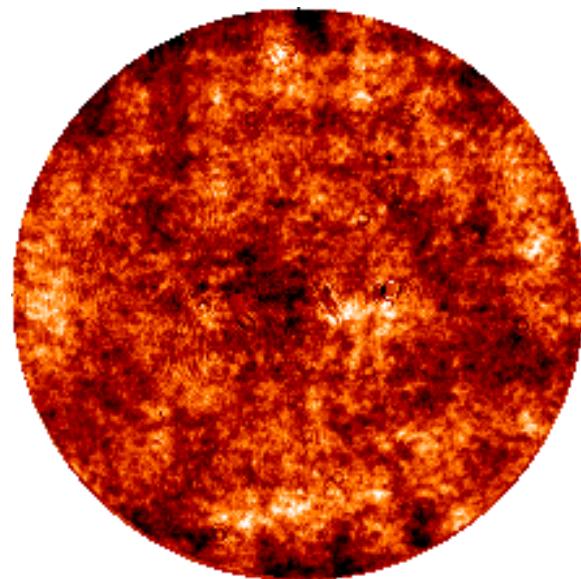
0.49 nm rms



Typical Field Point
All freq. included < 20 cycles/NA

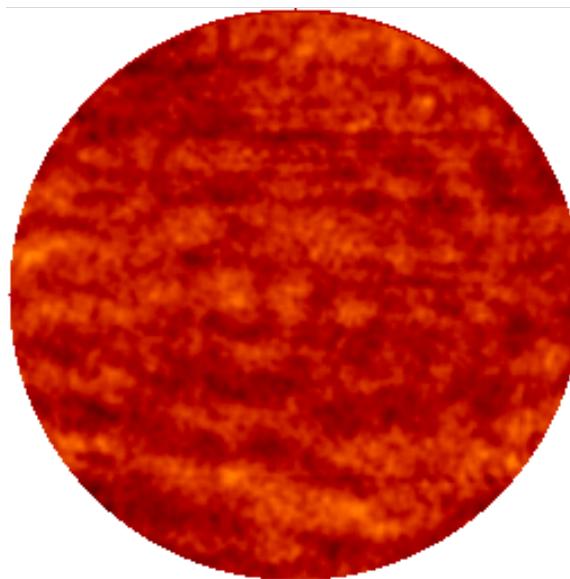
Optics Set 2 promises a substantial improvement in wavefront quality

Optics Set 1

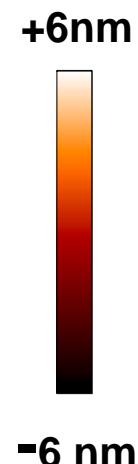


2.02 nm rms

Optics Set 2



0.77 nm rms

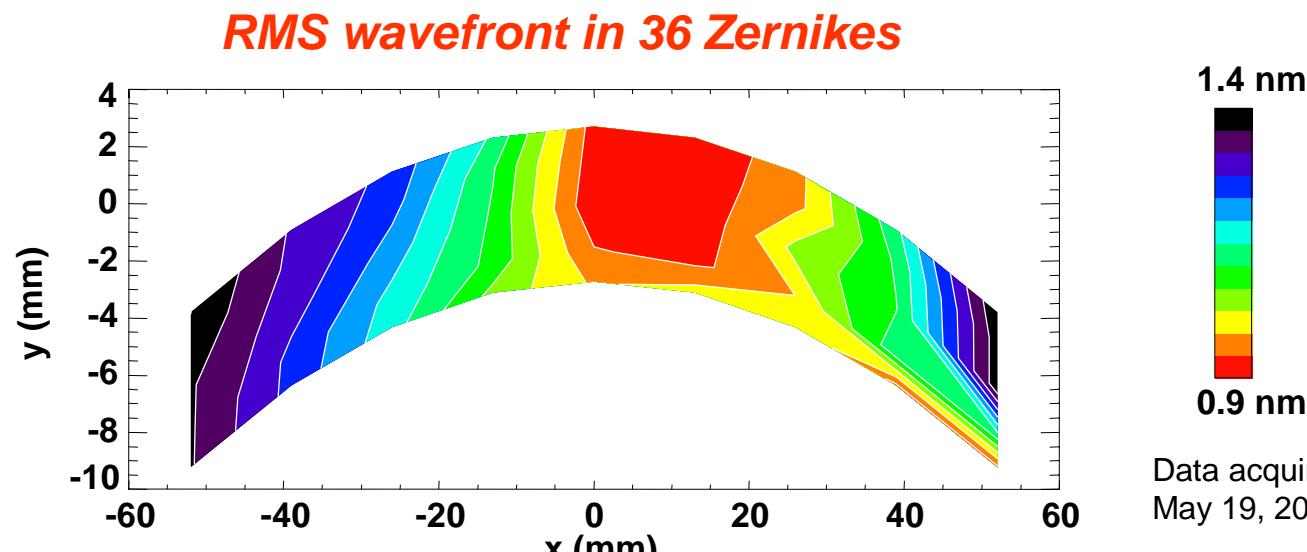


Spatial Frequencies: $0 < f < 54$ cycles/NA

Optics Set 2 promises a substantial improvement in wavefront quality and uniformity across the field

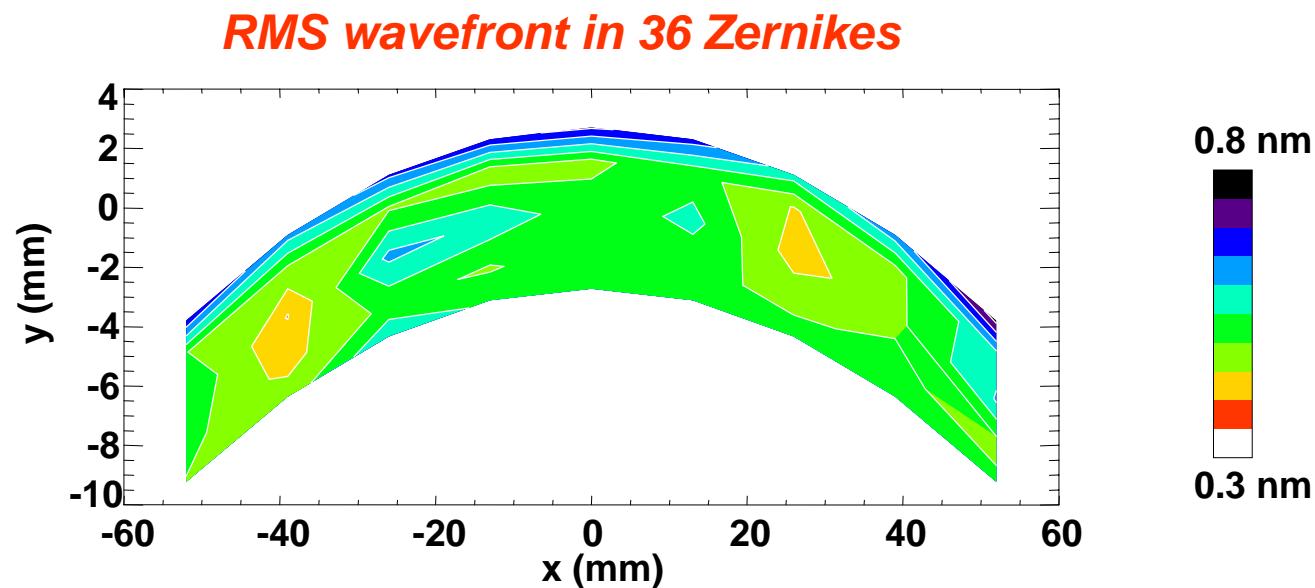
Measured WFE for
Optics Set 1

Mean RMS wavefront
across field: 1.20 nm

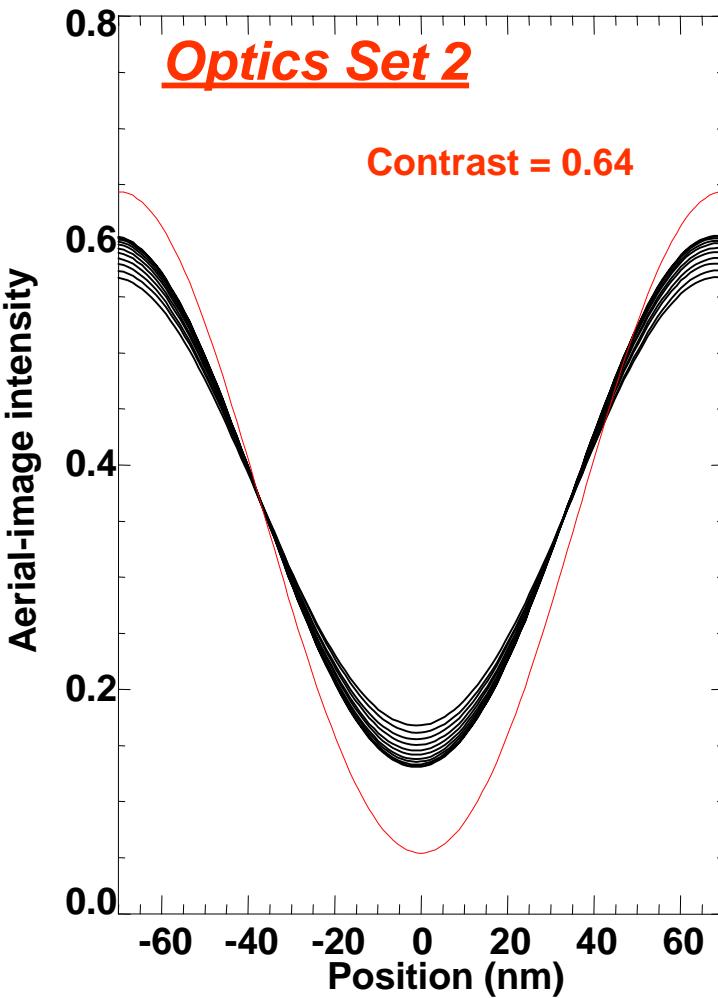
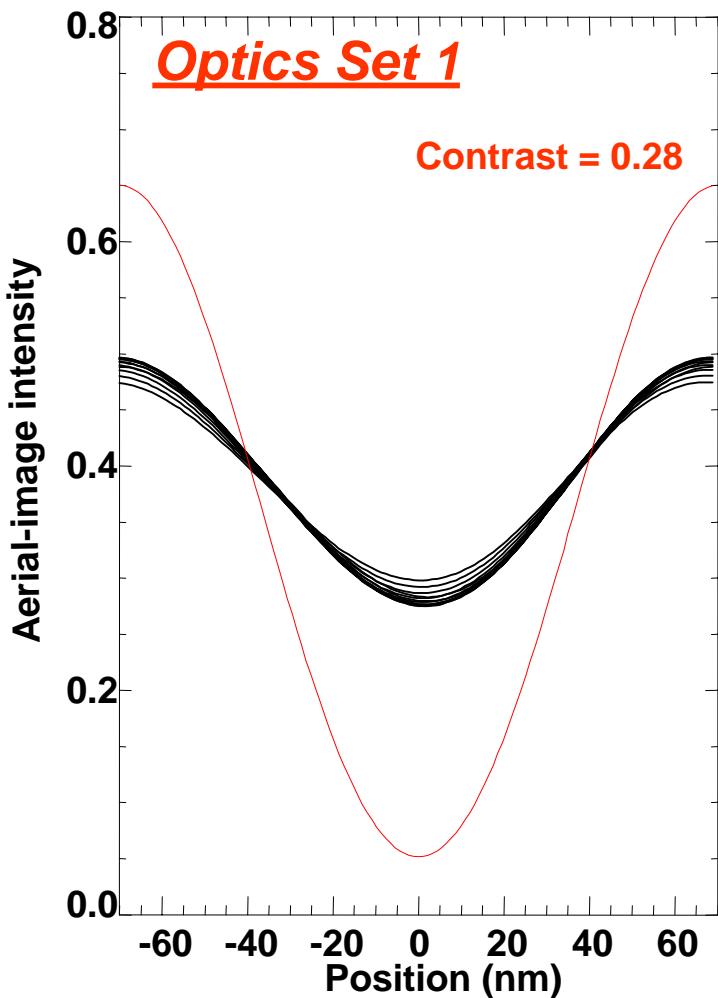


Prediction for
Optics Set 2

Mean RMS wavefront
across field: 0.52 nm



Calculated static aerial images of 70 nm dense lines show a major improvement with Optics Set 2

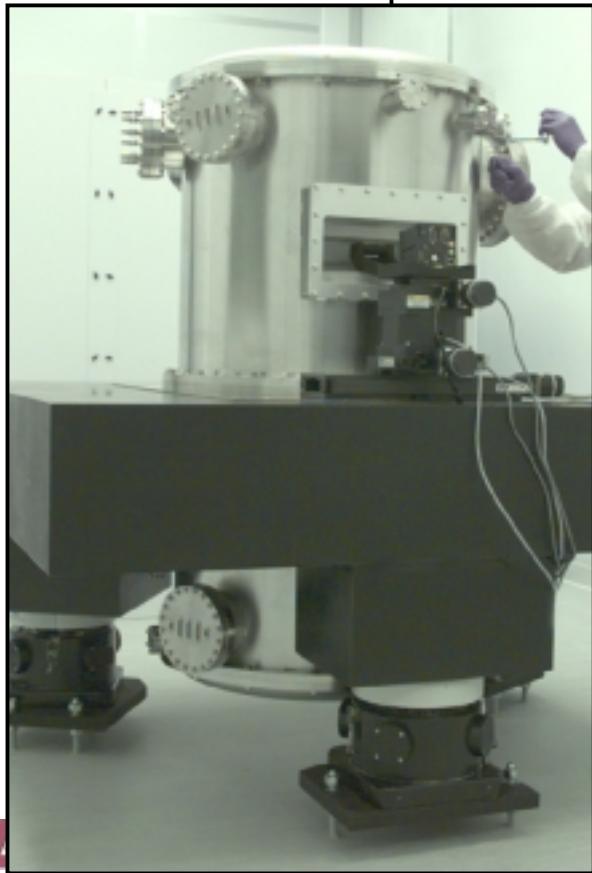


— Diffraction-limited image

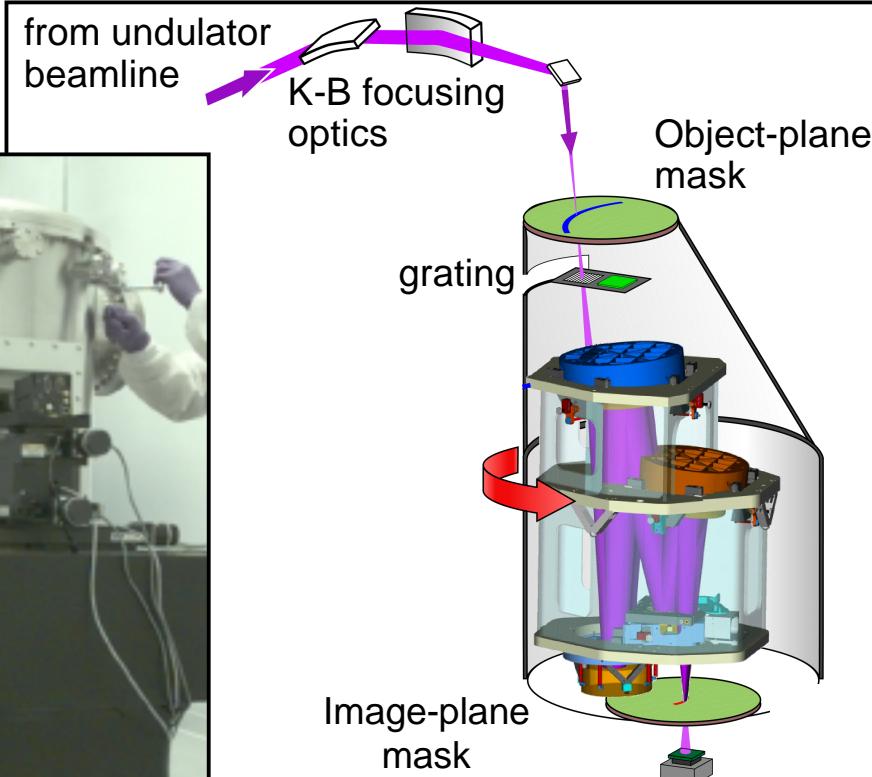
Computed deterministically for $f < 54$ cycles per NA,
statistically for $54 < f < 2500$ per NA

Key system tests are planned for PO Box 2 in 2001

Visible Light Interferometry and Alignment



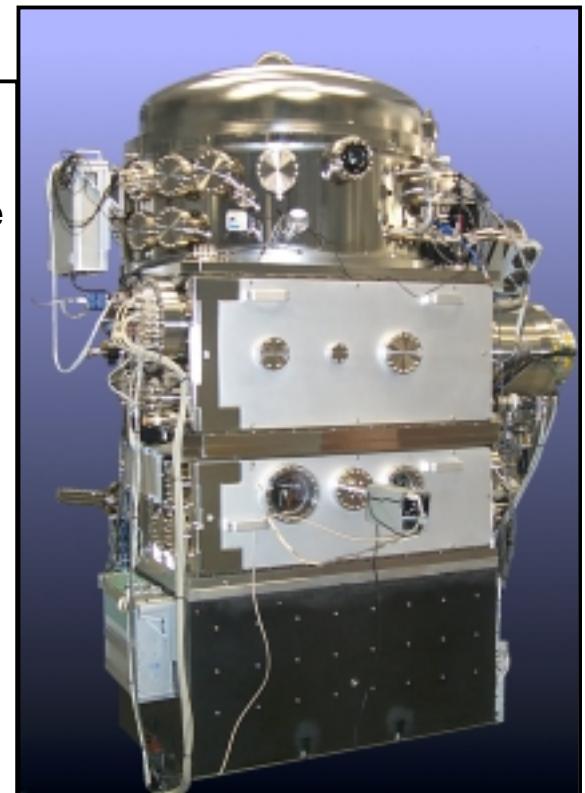
Interferometry and Static Printing at the Advanced Light Source



Q1 – 2001

Q2-3 – 2001

Installation into the Engineering Test Stand



Q4 – 2001

PO Box 2 will meet 70 nm (dense) imaging requirements

Workshop papers

Optical Fabrication

Lou Marchetti

- Optics Set 2 has greatly improved figure errors and surface finish

Multilayer Coating

Jim Folta

- Optics Set 1 achieved *production quality* uniformity

Mechanical Assembly

Layton Hale

- Optics Set 1 achieved was well within capture tolerance

Optical Alignment

Henry Chapman

- Lower distortion alignment planned for PO Box 2

At- λ Characterization

Ken Goldberg, Patrick Naulleau

- System WFE at EUV is shown to be same as with visible light